Nonlocal Electron Transport in Laser-produced Plasmas

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Kinetic modeling on laser-produced plasmas

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Kinetic Physics Workshop
Thursday, April 5th- 7th 2016
at Lawrence Livermore National Laboratory

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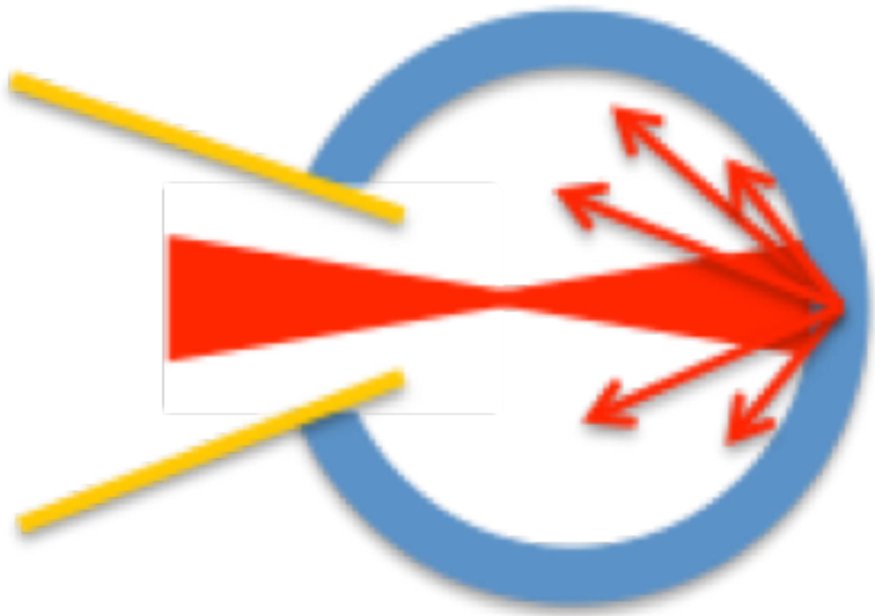
- Fokker-Planck equation for nonlocal electron transport in laser implosion
- Spark generation experiment
- Plan of developing Direct Simulation Monte Carlo (DSMC) with Langevin dynamics
- Particle in cell (PIC) simulation on comparison of Braginskii and Ji-Held.

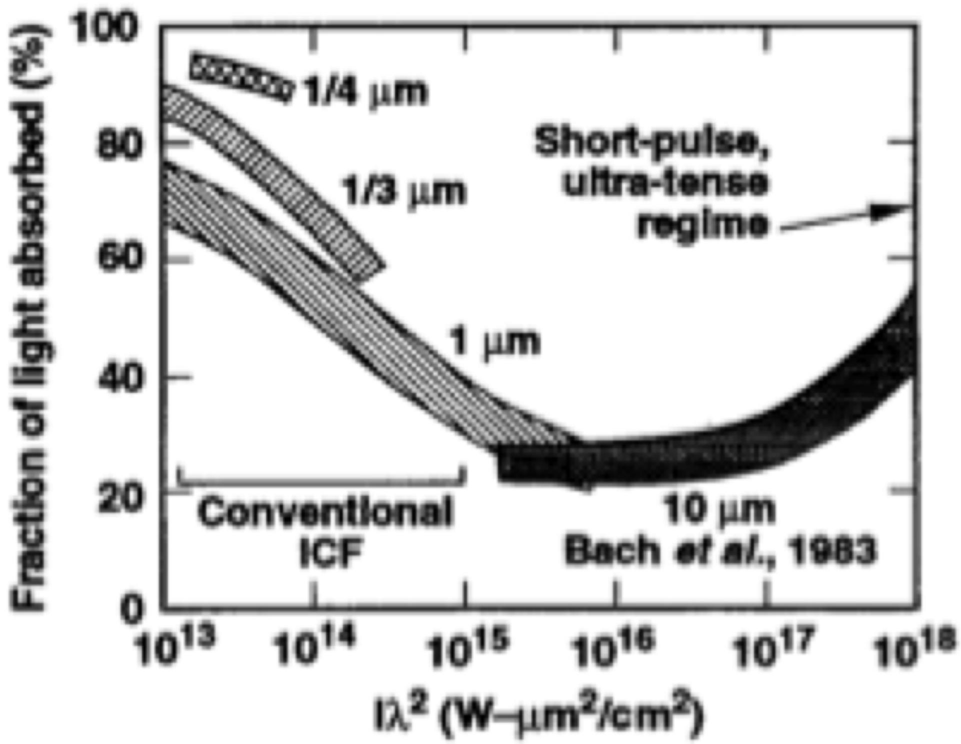
Exp

We have conducted the spark formation experiment by multiple reflection of laser inside CD shell.

500μm diameter
7μm thickness CD shell



1μm wavelength laser
100ps duration
167μmΦ spot
$I_L = 8 \times 10^{16} W/cm^2$



Ignition and high gain with ultrapowerful lasers*

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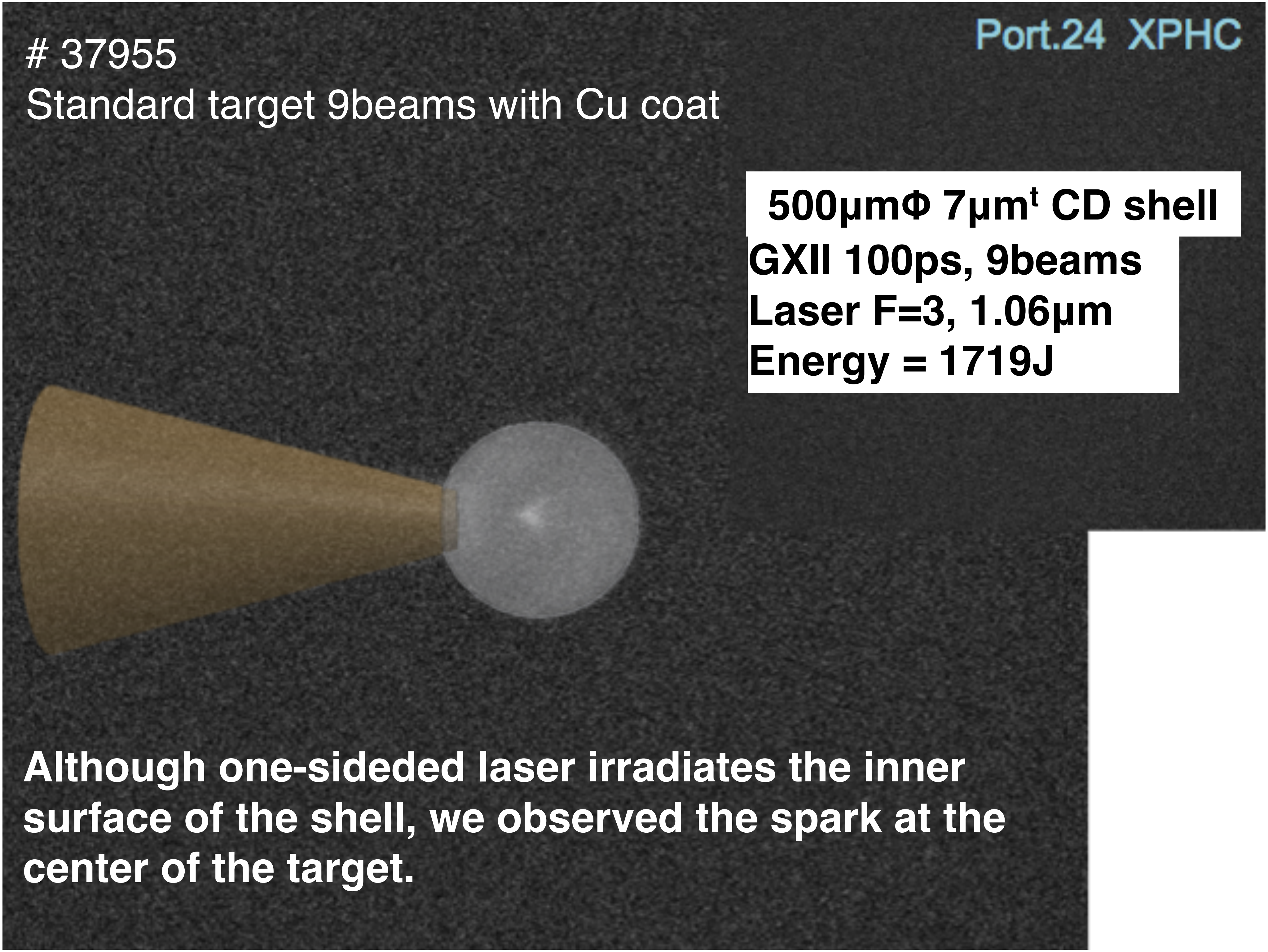
(Received 5 November 1993; accepted 12 January 1994)

Ultrahigh intensity lasers can potentially be used in conjunction with conventional fusion lasers to ignite inertial confinement fusion (ICF) capsules with a total energy of a few tens of kilojoules of laser light, and can possibly lead to high gain with as little as 100 kJ. A scheme is proposed with three phases. First, a capsule is imploded as in the conventional approach to inertial fusion to assemble a high-density fuel configuration. Second, a hole is bored through the capsule corona composed of ablated material, as the critical density is pushed close to the high-density core of the capsule by the ponderomotive force associated with high-intensity laser light. Finally, the fuel is ignited by suprathermal electrons, produced in the high-intensity laser–plasma interactions, which then propagate from critical density to this high-density core. This new scheme also drastically reduces the difficulty of the implosion, and thereby allows lower quality fabrication and less stringent beam quality and symmetry requirements from the implosion driver. The difficulty of the fusion scheme is transferred to the technological difficulty of producing the ultrahigh-intensity laser and of transporting this energy to the fuel.



37955
Standard target 9beams with Cu coat
Port.24 XPHC
500μmΦ 7μm^t CD shell
GXII 100ps, 9beams
Laser F=3, 1.06μm
Energy = 1719J
Although one-sideded laser irradiates the inner surface of the shell, we observed the spark at the center of the target.

Exp

Experiment

- Inner surface of 500μm diameter 7μm thickness CD shell was irradiated by the one-sided GXII 100ps, 1W, 1.7kJ,167μmΦ spot laser.
- Laser intensity is order of 8×10^{16} W/cm^2.

Results

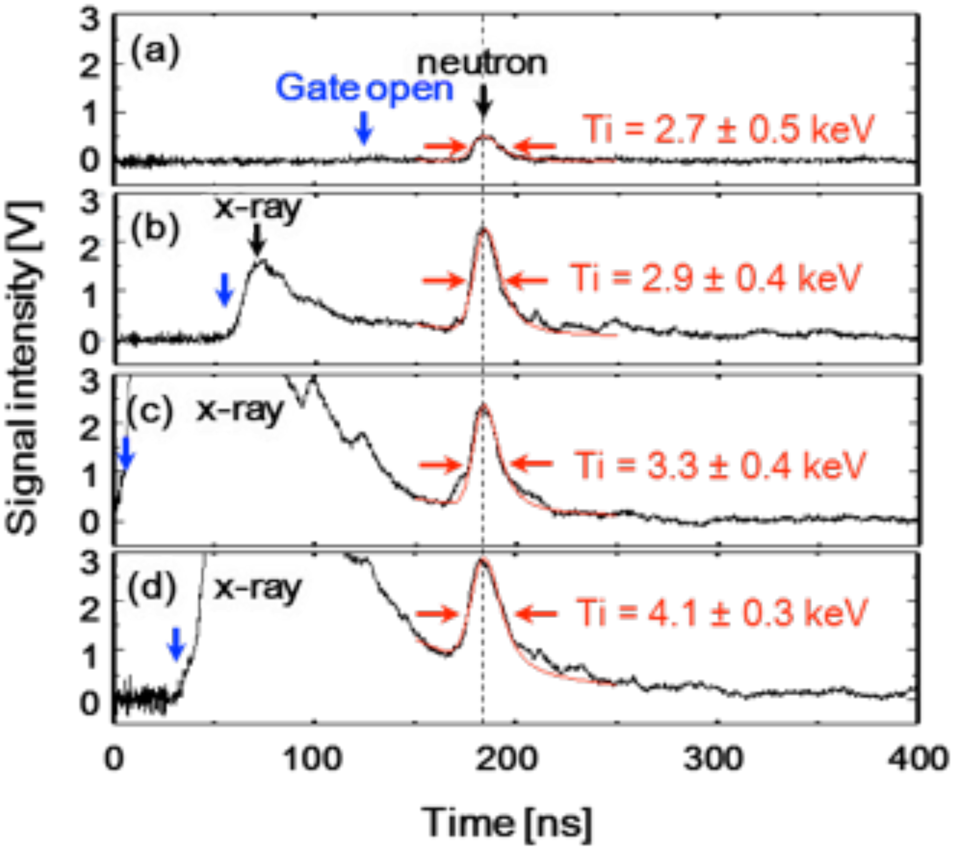
- From scattered light measurement, we estimate that 90% of heating laser energy was input into the interior of the shell.
- From neutron diagnostics, we obtained 3×10^7 DD yield, and Ti = 4.1keV
- From x-ray diagnostics, we estimate the plasma density of ~ 0.1 g/cm^3.
- We observed maximum expansion speed to be ~ 5x10^7 cm.s.

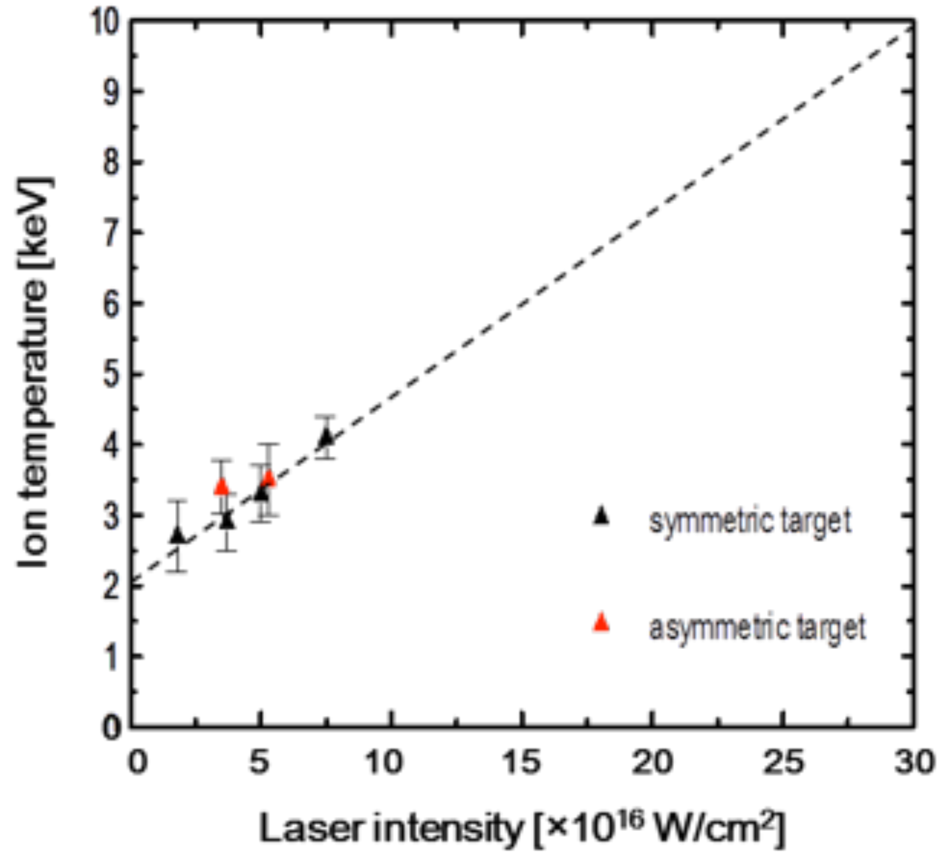
Ion Temperature

Exp

We measured the ion temperature from neutron spectrum.

47.5 degrees from the laser axis



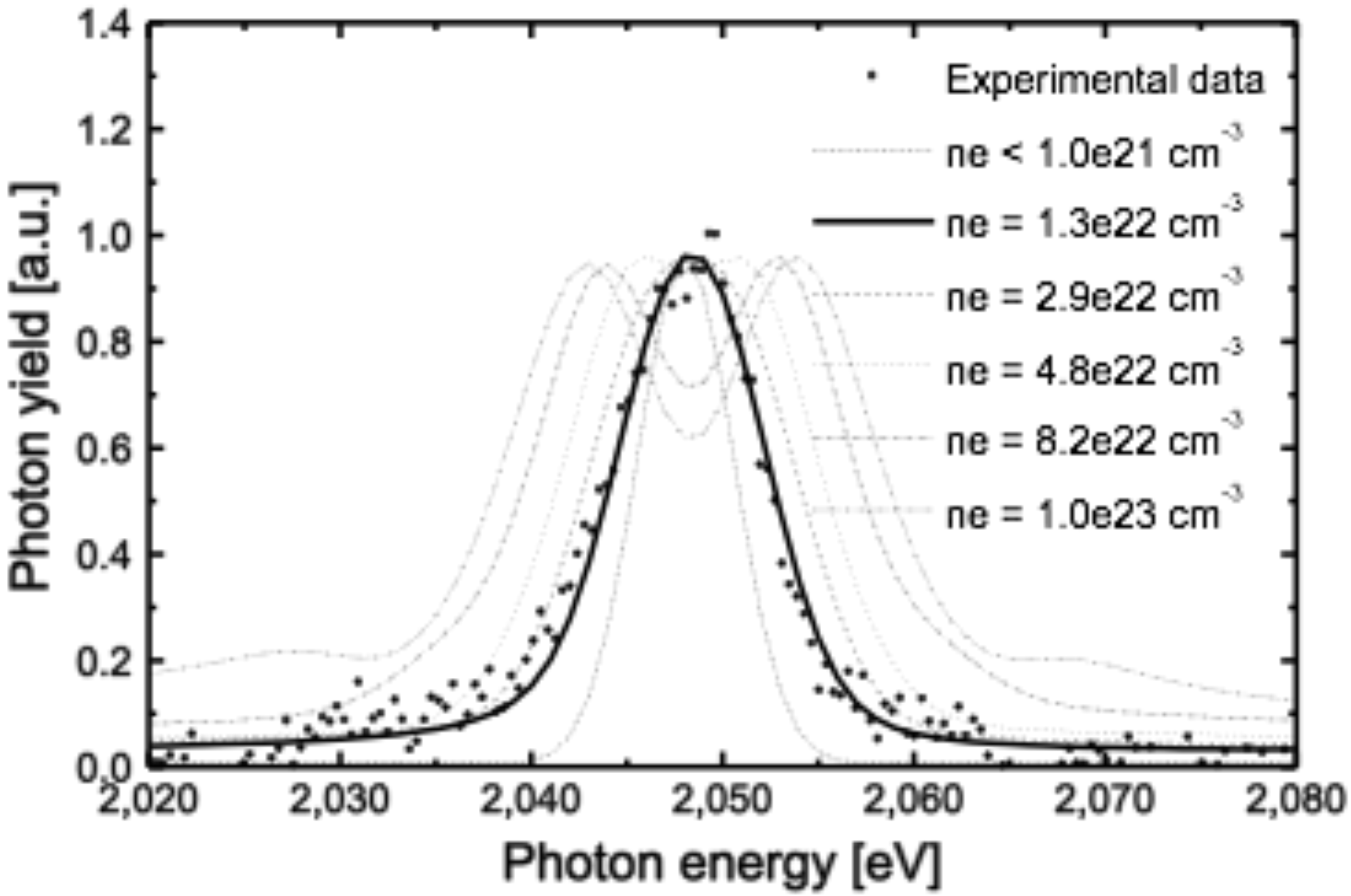


With 2.4kJ input, we observed ion temperature of 4.1keV.

Density

Exp

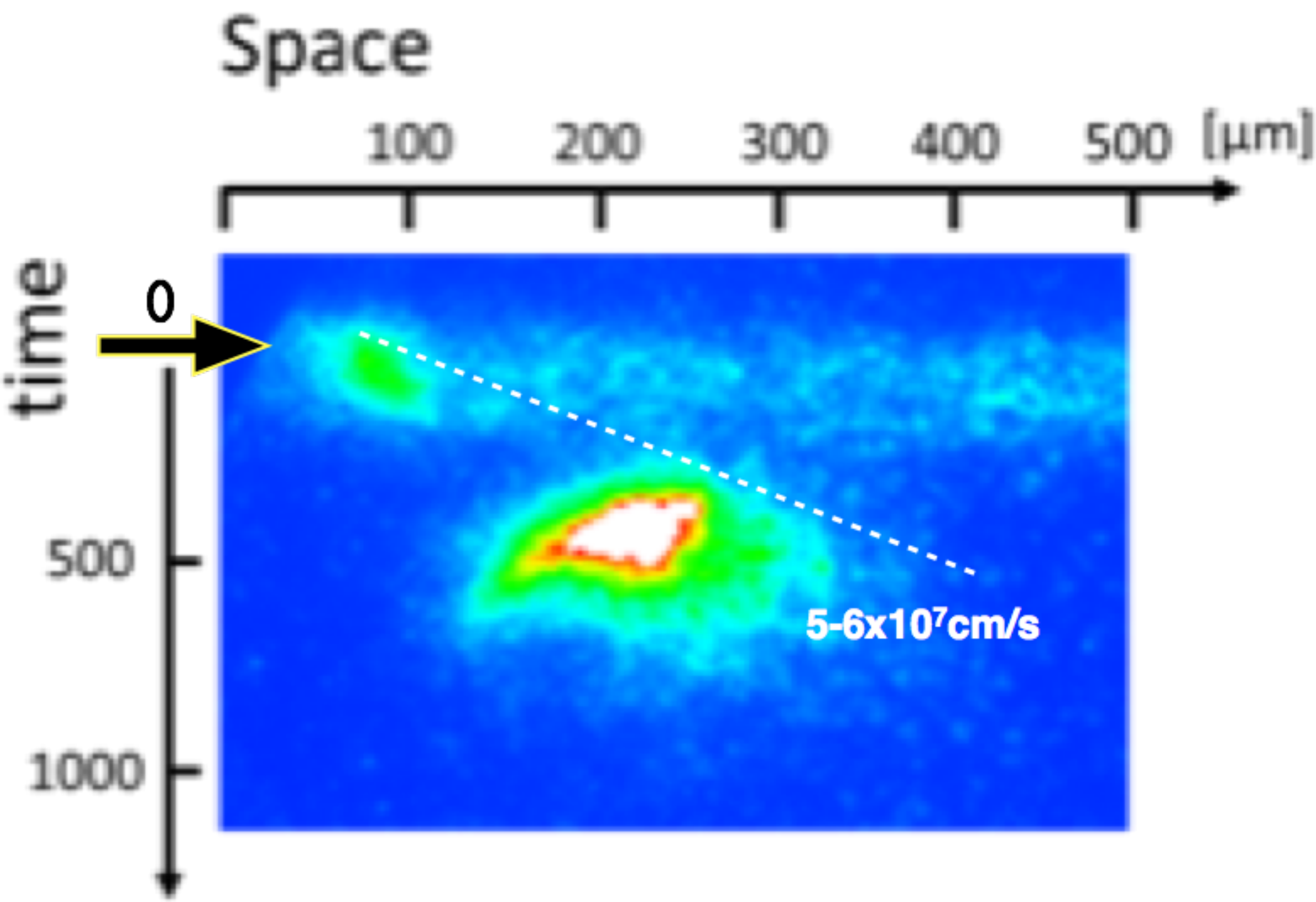
The energy distribution of *Ly*-β emission (2.048 keV) from Al plasmas recorded and compared with FLYCHK simulation. We estimated averaged electron density to be 1.4×10^{22} cm^{-3}. **~0.1g/cc**

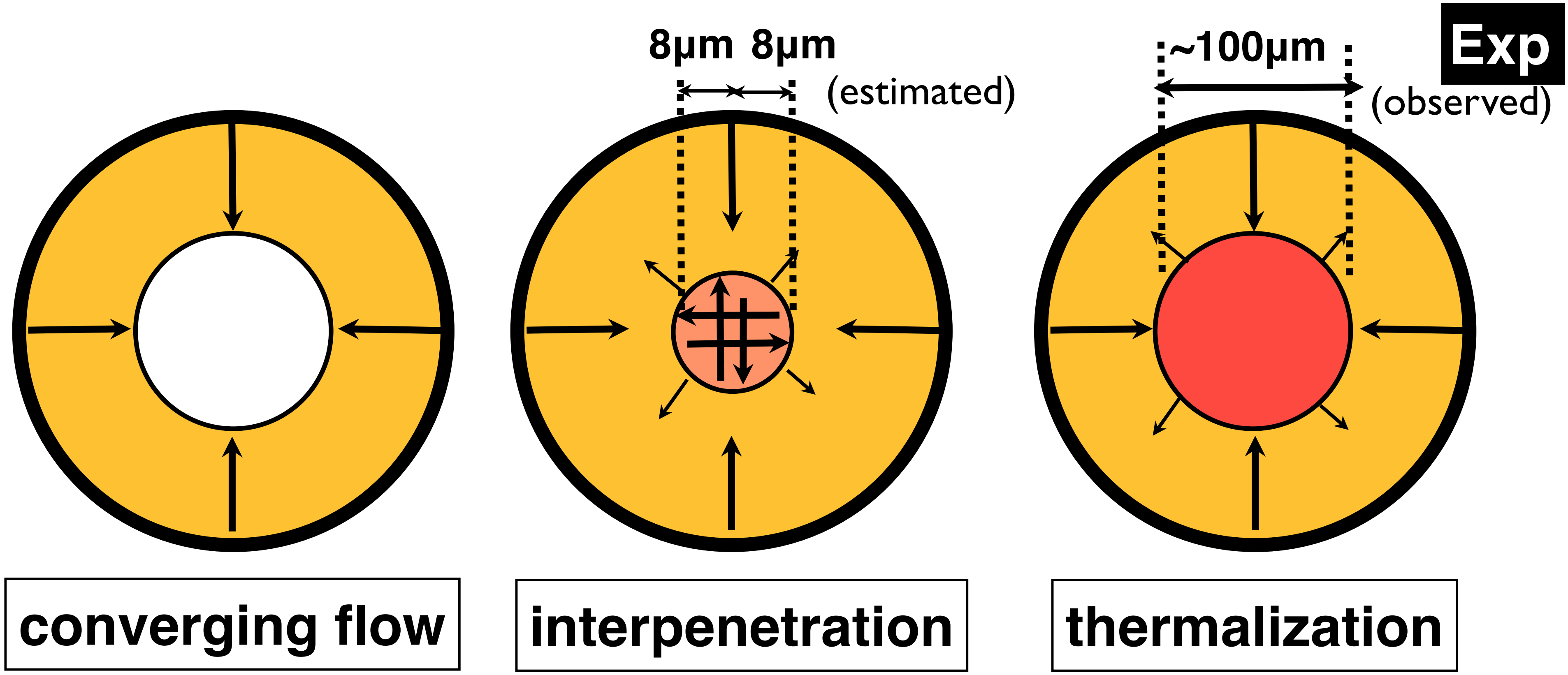


Density of hot spark is estimated to be order of 0.1 g/cm^3.

velocity

#37936 MIXS



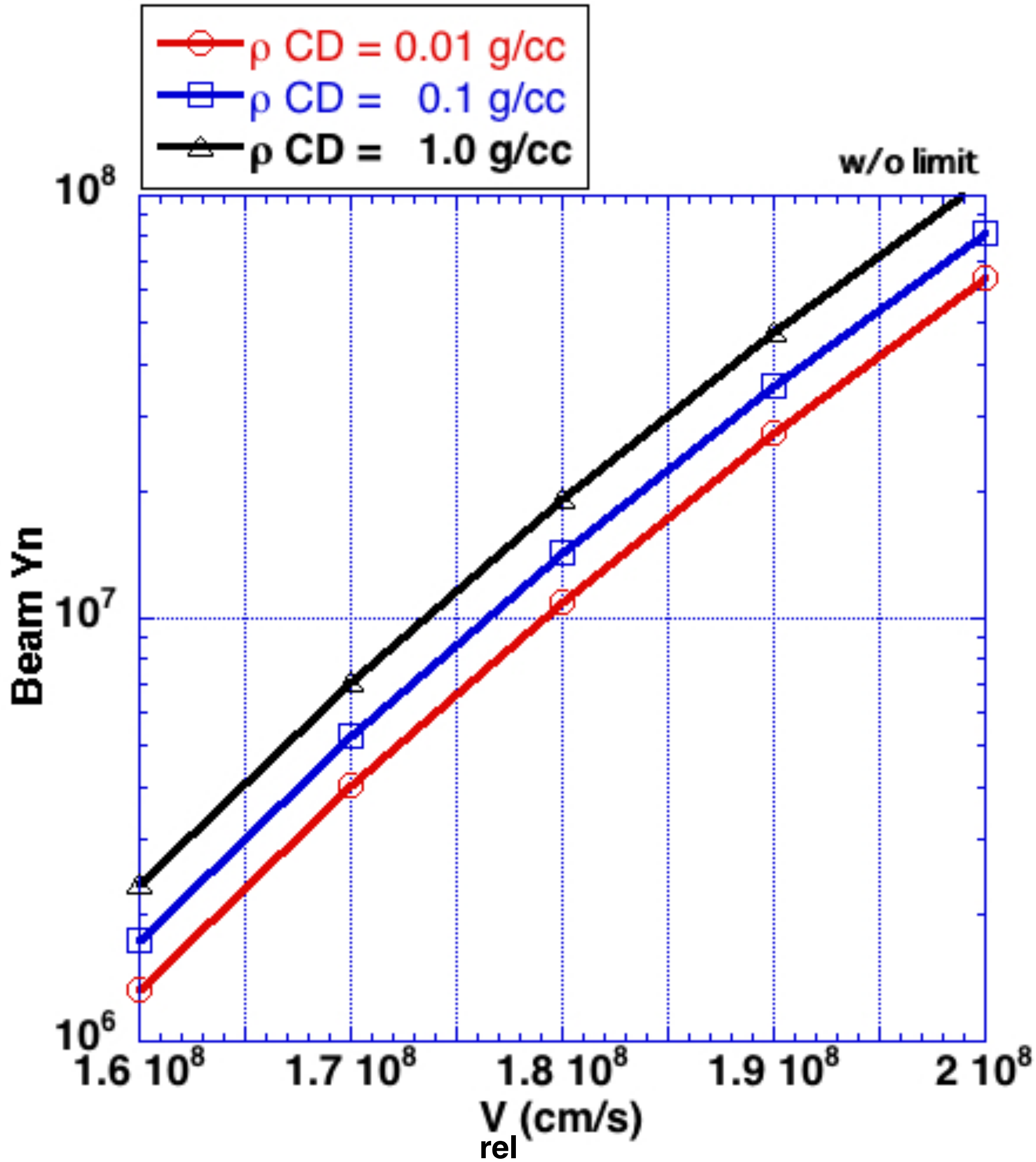


5E7cm/s -5E7cm/s

V_{rel} (c^{6+}, c^{6+})= 1E8cm/s

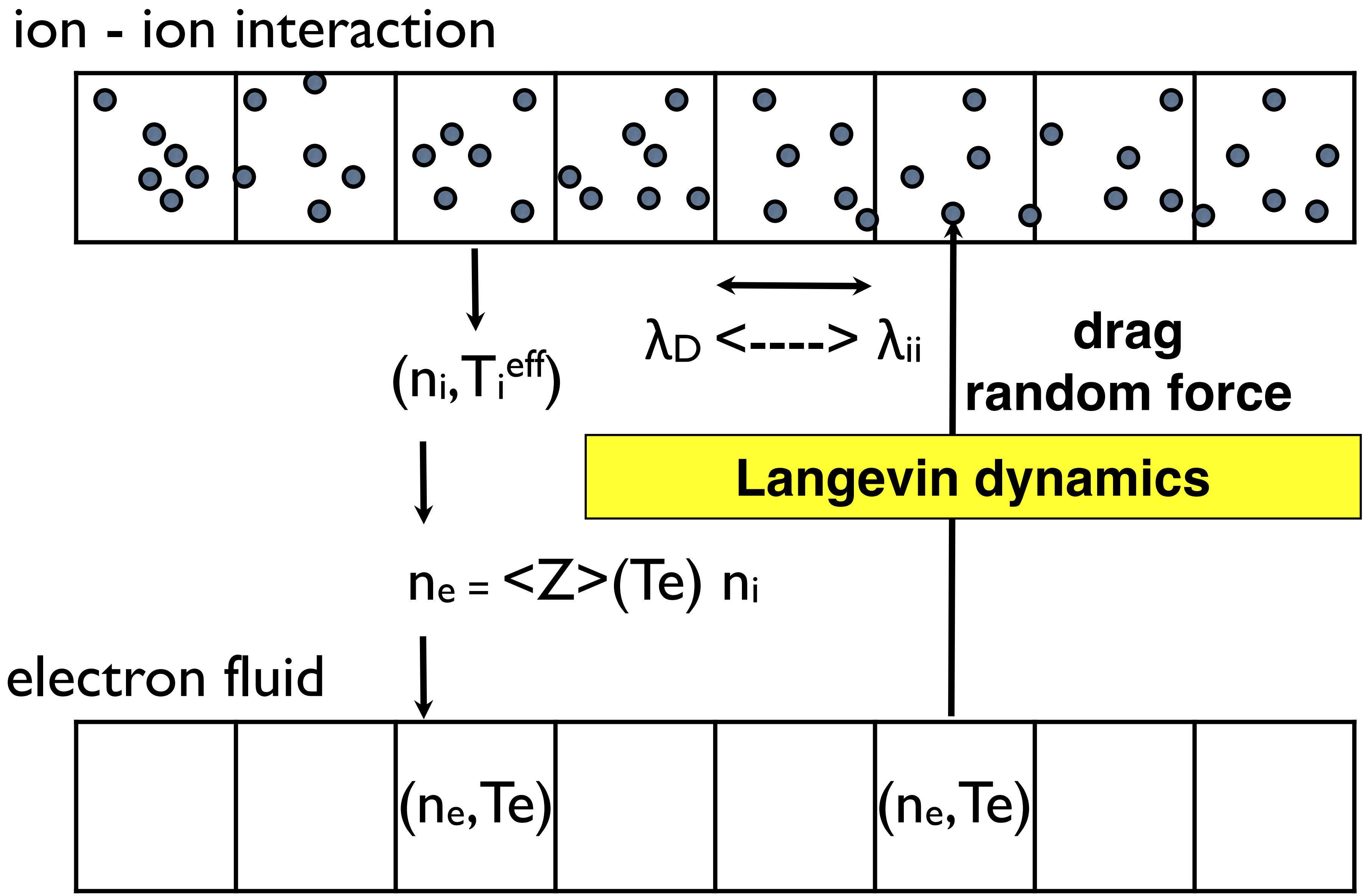
$$\lambda_{tj} = \frac{4\pi\epsilon_0^2 M_t^2 V^4}{n_j e^4 Z_t^2 Z_j^2 (1 + M_t/M_j)\, ln\Lambda_{tj}}$$

Assuming ρ_{CD} = 0.1g/cc, collision length is calculated to be λ_{CC}=8μm, λ_{CD}=12μm, and λ_{DD}=200μm, respectively.



For V_{rel} = 1E8cm/s, beam DD neutron is negligible to the thermal component.

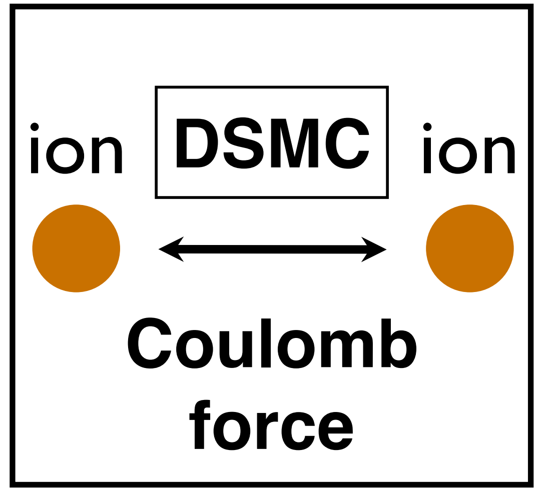
Direct Simulation Monte Carlo[1] with Langevin dynamics



1) G. A. Bird, Molecular Gas Dynamics and the Direct Simulation of Gas Flows, Claredon, Oxford (1994)

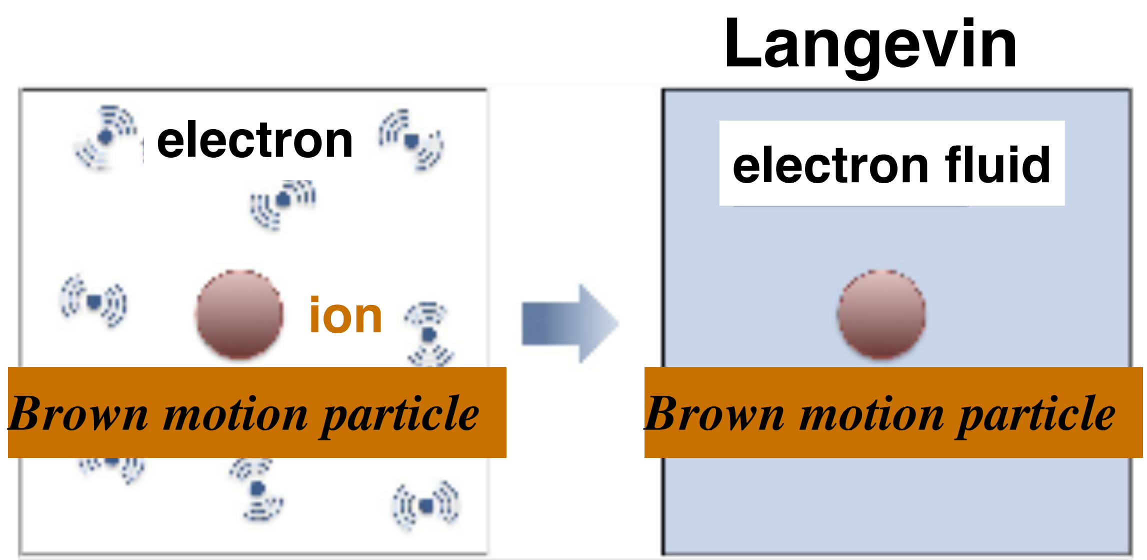
ion equation of motion

$$m_i \frac{dv}{dt} = \underbrace{F}_{\text{dsmc}} - \underbrace{\gamma v}_{\text{drag}} + \underbrace{R}_{\text{random}}$$



electron energy equation

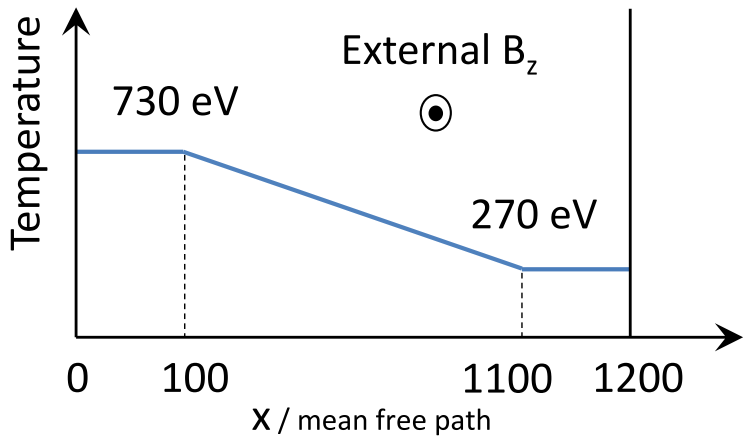
$$n_e c_e k_B \frac{\partial T_e}{\partial t} = \underbrace{\nabla(\kappa_e \nabla T_e)}_{\text{conduction}} - \underbrace{g(T_e - T_{i\ \mathrm{eff}})}_{\text{relaxation}} + \underbrace{H_e}_{\text{other terms}}$$



PIC

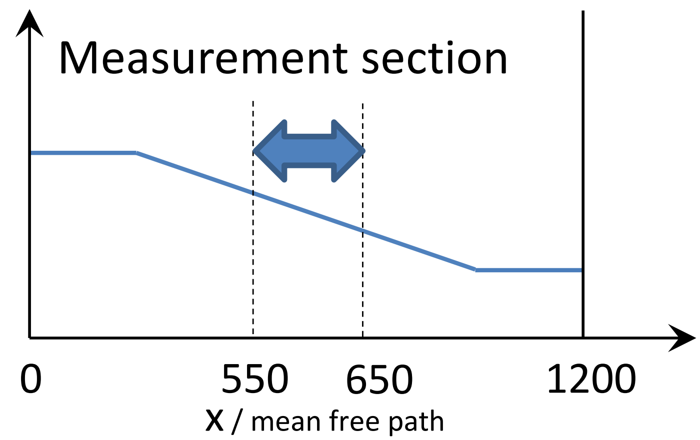
Validation of thermal conductivity models using 1D PIC simulation

Initial condition



- Electron density $n_e = 5 \times 10^{22}$ cm^{-3}
- External B-field $\omega_{ce}\tau_{ei}$ = 0-0.9
- Ion charge state $Z = 4$
- Ion mass $m_i/m_e = 10^4$
- Calculation time $100\tau_{ei}$
- # of cells 4200
- # of particles 4.2×10^8

Thermal conductivity measurement



Heat flux: $\mathbf{q} = \int (1/2) m v^2 \mathbf{v} f(\mathbf{v}) d\mathbf{v}$

Thermal conductivity:

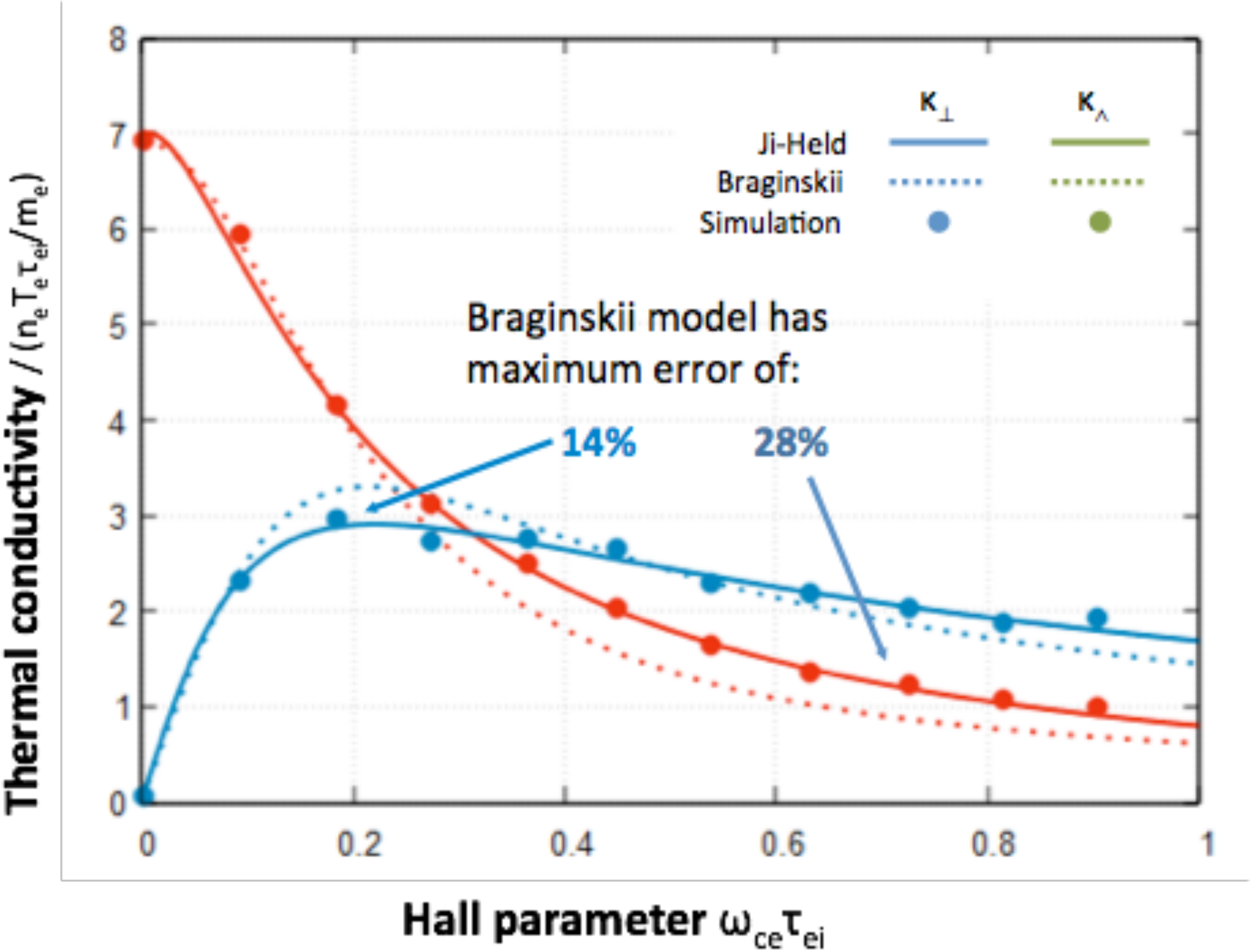
$$\kappa_{\perp} = -q_x / (dT/dx)$$

$$\kappa_{\wedge} = -q_y / (dT/dx)$$

[*1]

PIC

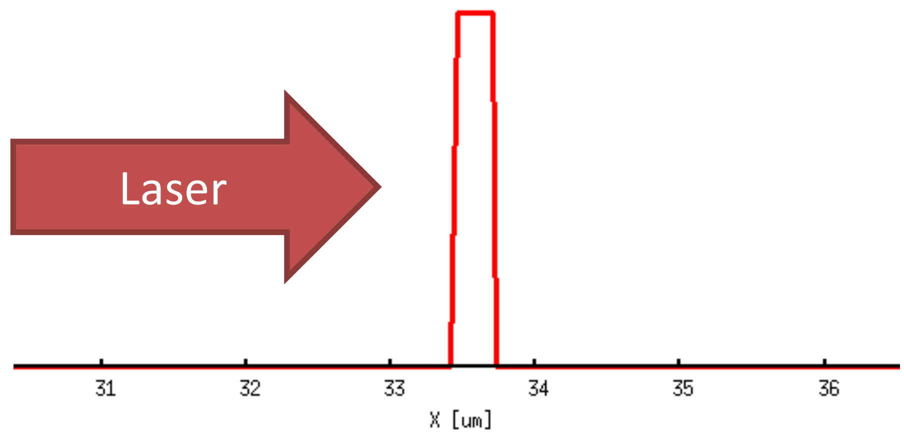
Ji-Held model was validated by the PIC simulation



[*1] J.-Y. Ji and E. D. Held, Phys. Plasmas 20 (2013) 042114.

1D PIC simulation of laser ablation

- Target
  - Carbon, fully ionized
  - 0.2 µmt
  - $n_e = 25 n_{critical}$
  - Particles are initially at rest

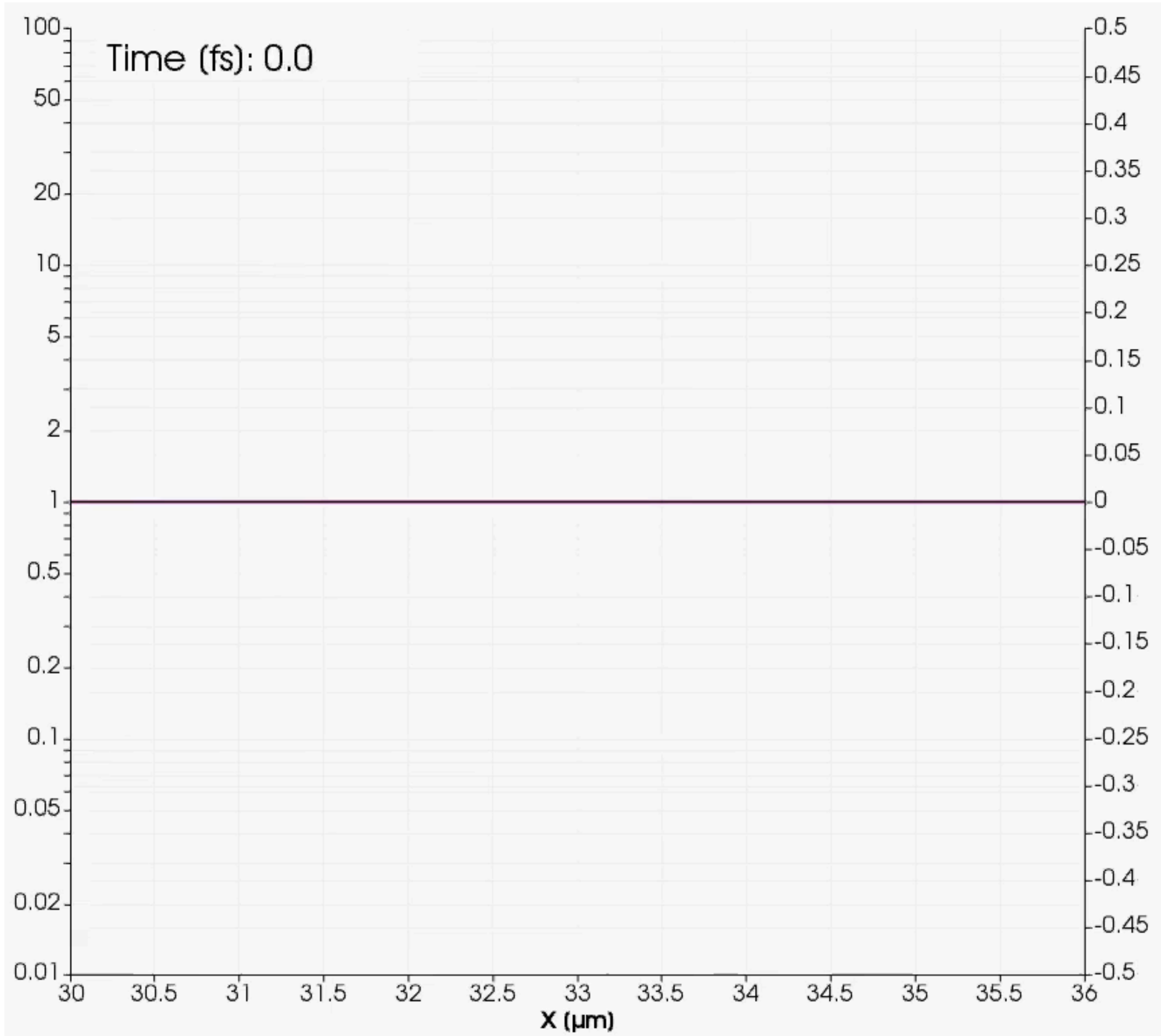


- Laser
  - $\lambda_L = 0.35\ \mu m$
  - $I_L = 5 \times 10^{14}\ W/cm^2$

Heat flux inhibition is confirmed by PIC simulation

Electron density [$n_{critical}$]

Electron temp. [keV]



Spitzer-Härm heat flux [$n_e T_e v_{th}$]

Actual heat flux [$n_e T_e v_{th}$]

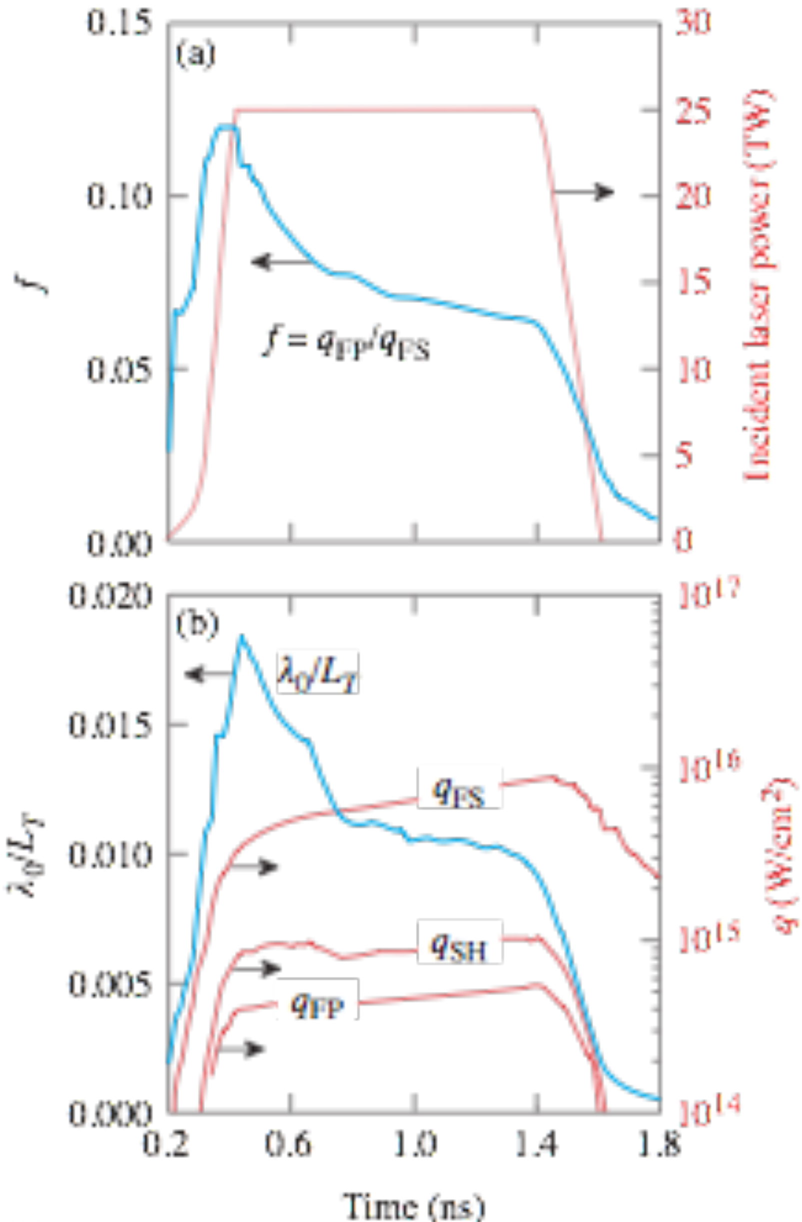
Summary

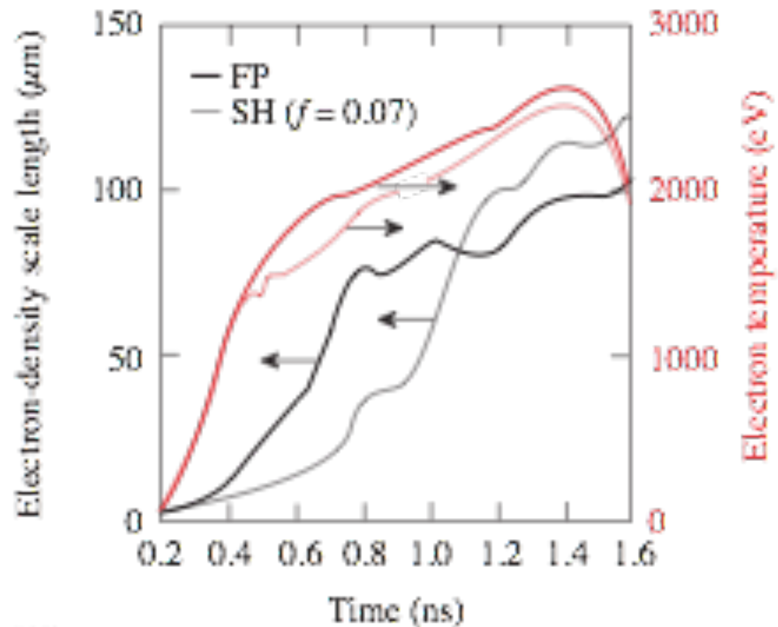
- Nonlocal electron thermal transport is critical issue for the laser-produced plasma, and direct-implosions.
  Robust simulation scheme should be developed.
- We conducted the hot spark generation experiment by inner irradiation scheme. In order to analyze observation, we are developing a DSMC code with Langevin dynamics.
- Validation of thermal conductivity models under magnetic fields using 1D PIC simulation has conducted.
  - The simulation showed that Ji-Held model is valid and Braginskii model has an error up to 28%.
- Investigation of nonlocal transport in ablation plasmas
  - 1D PIC simulation showed the flux inhibition.

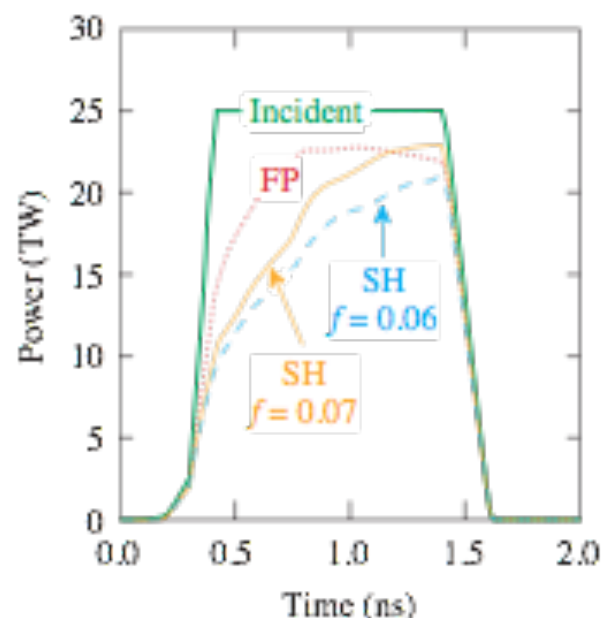
Additional viewgraphs

FP

0.35μm 1ns pulse
900μm CH shell with 20μm thickness
filled with 15atm of D2 gas





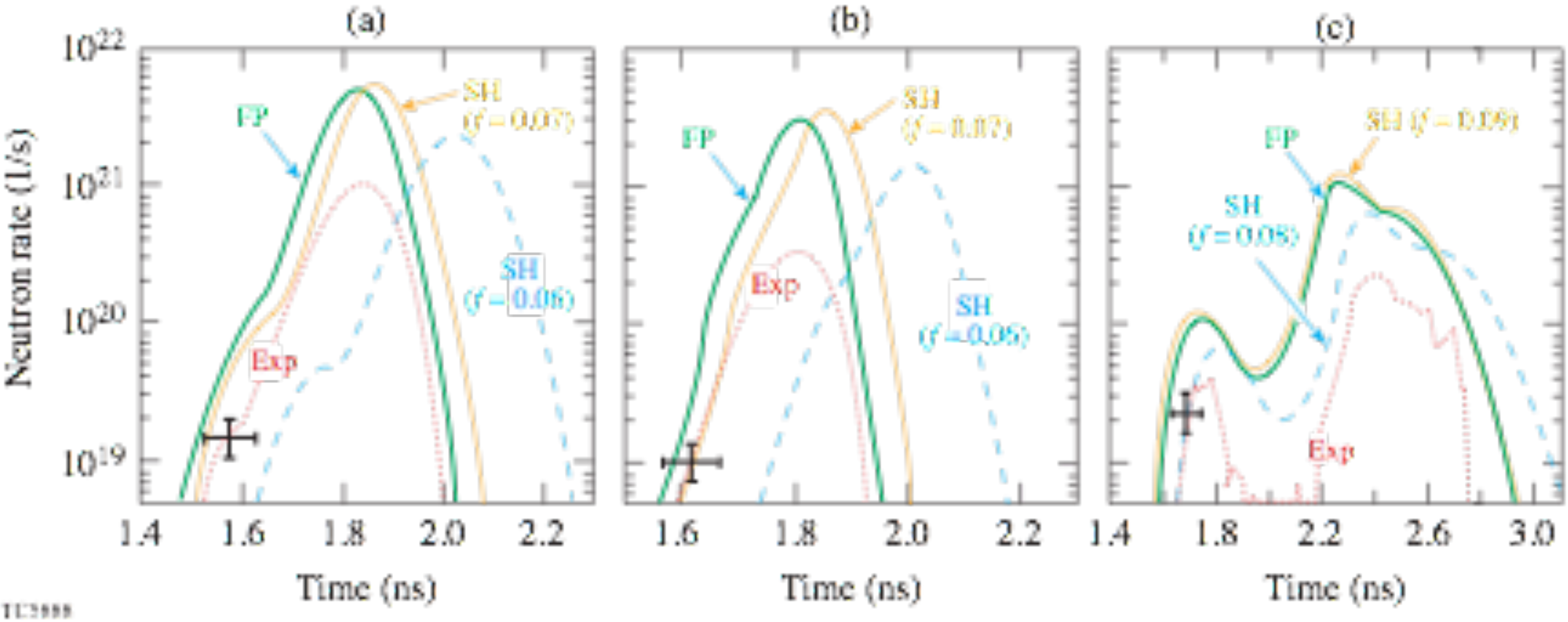


FP

15atm of D2 gas
1ns square

3atm of D2 gas
1ns square

20atm of D2 gas
0.4ns square



Time-Dependent Electron Thermal Flux Inhibition in Direct-Drive Laser Implosions

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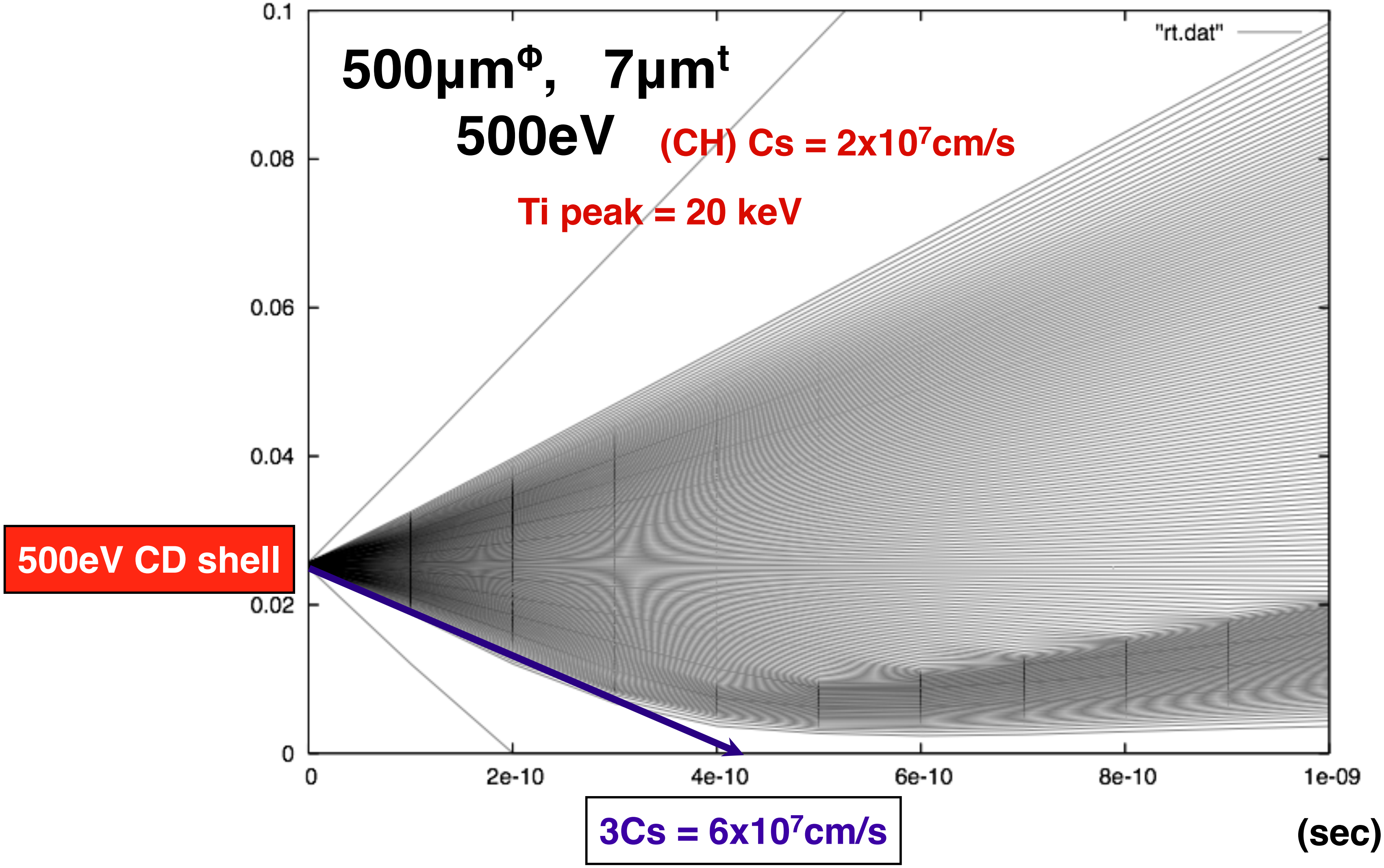
(Received 11 February 2002; published 28 August 2003)

CD 500μm$^{\Phi}$, 7μm^{t}, shell
T_{init}= 500eV



Star1D simulation confirmed that the front velocity of rarefaction can reach to 3x initial sound velocity

Slower electrons contribute to the conduction in magnetic fields

$$\mathbf{q} = \int (1/2) m v^2 \mathbf{v} f(\mathbf{v}) d\mathbf{v}$$
$$= \int \mathbf{g}(v) dv$$

Angular integration

Magnetic field shortens the energy transport distance from mean free path (~v^4) to Larmor radius (~v).